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Formaldehyde Exposure and Health Status in Households

by I. Broder,* P. Corey,† P. Brasher,‡ M. Lipa,§ and P. Cole//

This report describes a case study concerned with acute and subacute health effects of formaldehyde in the indoor air, which is based on a large group of control houses and houses retroinsulated 4 to 5 years earlier with urea formaldehyde foam insulation (UFFI). Both groups underwent an environmental and health assessment on two occasions separated by an interval of 12 months, during which about one-half of the UFFI group performed remedial work on their houses. The results show that in the first survey of the study population, before remedial work, there was a moderate excess of many adverse health status indicators among the UFFI subset relative to the controls. This was associated with the presence of direct exposure–response relationships between formaldehyde levels in the UFFI houses and the prevalence of a number of symptoms. No comparable relationships were seen among the controls. At the second survey, performed following the removal of the UFFI, there was an appreciable reduction in the excess of most adverse health status indicators among the UFFI subjects. This improvement in health status among the UFFI removal subset was not associated with any significant diminution of formaldehyde exposures, although the previously observed exposure–response relationships had vanished. These observations imply that the findings obtained in the preremedial stage of the study cannot be explained by formaldehyde exposure alone.

Introduction

Formaldehyde has long been known to have acute surface irritant effects on humans, as indicated mainly by observations made in industry. Based on whether the exposed individual is highly sensitive or average in sensitivity, ocular irritation is observed at between 0.05 ppm and 1.0 ppm, nasal and throat effects at 0.1 to 1.0 ppm, and cough at 5 to 30 ppm. Less information is available relevant to the nonindustrial indoor setting (*1–7*).

The following report describes a case study concerned with acute and subacute health effects of formaldehyde in the indoor air, which is based on a large group of control houses and houses retroinsulated 4 to 5 years earlier with urea formaldehyde foam insulation (UFFI). The field work was done during the period 1983 to 1985, and the main publications appeared in 1988 (*6–8*).

The objective of the study was to compare the health status between the control and UFFI households and, if differences were found, to examine the role of formaldehyde exposure. This study was conducted at a time when the Government of Canada was providing subsidies for UFFI remedial work. Thus a longitudinal component was included in the study to allow the efficacy of the remedial measures to be assessed.

The data are presented here in a manner focusing on an unexpected finding encountered in this study, rather than on the adverse effects of UFFI and the efficacy of remedial work, which have been the focus of the earlier publications (*6–8*). This finding is of interest in this workshop because it exemplifies the complex nature of the adverse human responses which seem to be attributable to the indoor environment.

Methods

The methodology of this study has been described in detail previously (*6*). Our study was based on about 200 control and 600 UFFI households, each of which was examined on two occasions separated by an interval of 12 months. Between the two surveys, about one-half of the UFFI houses underwent remedial work. The UFFI households that were enrolled consisted of three subsets based on their intention either to have the UFFI removed, to do other remedial work such as sealing the UFFI-insulated wall cavities, or to remain unchanged. Houses were entered into the study in sets of four consisting of one control and one of each of the three UFFI subsets. These sets were matched by location, to be within about 1 mile of each other, and by time of entry, to undergo their initial assessment within the same 4- to 6-week period.

*The Gage Research Institute, University of Toronto, Toronto, Ontario, Canada, M5T 1R4.
†Department of Medicine, University of Toronto, Toronto, Ontario, Canada, M5T 1R4.
‡Department of Preventive Medicine and Biostatistics, University of Toronto, Toronto, Ontario, Canada, M5T 1R4.
§Department of Otolaryngology, University of Toronto, Toronto, Ontario, Canada, M5T 1R4.
//Department of Pathology, University of Toronto, Toronto, Ontario, Canada, M5T 1R4.
Address reprint requests to I. Broder, The Gage Research Institute, University of Toronto, 223 College Street, Toronto, Ontario, Canada, M5T 1R4.

The houses were assessed using a questionnaire that collected information about a variety of features, including construction details, ventilation, and pollution sources. Formaldehyde levels were monitored with a pump and impingers centrally, in all bedrooms, and outside the houses, on 2 sequential days, during the same period as the occupants were examined. Assays were performed by the chromatropic acid method, using rigorous quality control procedures, which included frequent blank, doped, and side-by-side field controls; regular calibration curves; split samples tested on an on-going basis in an independent laboratory; and blinding of our own technical staff as to the identity of the test samples (*6*). CO_2 levels, temperature, and humidity were measured centrally and outside on the same occasions as formaldehyde. The temperature and humidity results are not important in the findings to be described and will not be mentioned further.

The occupants were assessed using a questionnaire that collected demographic details as well as other information, including the presence or absence of a variety of symptoms, need for medical services, and history of active and passive smoking. Also, all subjects over the age of 16 underwent a series of tests including pulmonary spirometry, nasal airway resistance, sense of smell, nasal surface inflammatory cell and epithelial cytology, and patch test for formaldehyde allergy. The results of the objective tests are not relevant to the information being described here and will not be given below. However, these tests did assist in establishing the credibility of the data base by demonstrating a number of expected relationships, such as the influence of age, gender, and smoking on pulmonary function and the association of respiratory symptoms with changes in the tests of pulmonary function and nasal resistance (*8*).

Results and Discussion

The first survey in this study was based on the 2446 occupants of 802 houses, all located within about 60 miles of central Toronto. About 90% participated in the second survey (*8*). The findings of this study were mainly explained by differences between the controls and the UFFI subset that underwent removal of their insulation. Accordingly, the results to be described will be simplified by dealing only with the 605 controls and 699 UFFI removal subjects, all of whom participated in both the first and second surveys.

The general characteristics of the control and UFFI removal subjects were quite similar as seen at the first survey, before remedial work (Table 1). The two groups did not differ significantly in racial origin, height, gender distribution, age, broad occupational categories, and in hours spent in the house per week. There was a nonsignificant trend for more of the UFFI removal subset to have been lifetime nonsmokers. Among those who were current or ex-smokers, the extent of smoking expressed as pack years was similar in both groups.

The prevalence and means of adverse health status indicators at the first survey, before any remedial work, was moderately higher for a large number of variables among the UFFI removal subset relative to the controls (Table 2). The risk ratio ranged from a low of 1.2 and 1.4 for number of colds in the preceding year and skin problem, through an intermediate level of 1.9 and 2.0 for eye irritation and number of days of time loss in the preceding year due to illness, to a high of 3.0 and 3.2 for increased thirst and throat discomfort. For the purpose of simplification only selected indicators will appear in subsequent tables, but this will preserve a representative picture of the findings.

Table 1. General characteristics of subjects.[a]

	Control, survey 1	Pre-UFFI removal, survey 1
No. of occupants	605	699
Caucasian, %	97	95
Height, cm	169	168
Female, %	52	50
Age, years	36	38
Occupation		
Home, %	25	27
White collar, %	33	30
Nonsmokers, %	32	39
Hours in house per week	116	119

[a]Characteristics at first survey of those occupants who were also seen at the second survey.

Table 2. Prevalence and means of health status indicators survey 1.

	% Reporting symptoms			
Indicator	Control	Pre-UFFI removal	p[a]	Risk ratio
Nasal problem	34	51	0.0001	1.5
Throat discomfort	5	16	0.0001	3.2
Eye irritation	13	25	0.0001	1.9
Skin problem	13	18	0.01	1.4
Cough	10	17	0.002	1.7
Sputum	7	11	0.05	1.6
Headache	17	24	0.001	1.4
Dizziness	4	10	0.0005	2.5
Tire easily	15	26	0.0001	1.7
Trouble hearing	11	18	0.0002	1.6
Increased thirst	4	12	0.0001	3.0
Constipation	3	8	0.0004	2.7
No. of subjects	605	699	—	—
No. days time loss	4.1	8.1	0.0003	2.0
No. colds in preceding year	1.8	2.1	0.004	1.2

[a]Groups were compared by the t-test and the chi-square statistic.

At the second survey, after remedial work had been performed by the UFFI removal subset, many of the statistically significant differences seen at the first survey had vanished, and those that remained were borderline (Table 3). There was a marked decrease in the risk ratio of some variables, such as throat discomfort and increased thirst; a moderate decrease in others, such as eye irritation and tiring easily; and no discernible change for a few, such as cough and sputum.

The average time interval between remedial work and survey 2 was 8 to 10 months, but the range was broad and in 20% the interval was 3 months or less. We accordingly examined the relationship between change in symptom prevalence from survey 1 and survey 2 and the number of days between remedial work being done and survey 2 (Table 4). This demonstrated a weak relationship for only the two variables nasal problem and headache, suggesting that the changes in health status that followed remedial work were generally independent of time before the second survey.

The house variables demonstrated that the UFFI removal homes were significantly older than the controls ($p = 0.0001$), which was expected since the controls would have been weighted with newer houses insulated with other materials at the time of being built and would not need to be retroinsulated (Table 5).

Table 3. Symptom prevalence, survey 2.

Symptom	% Reporting symptom			
	Control	Post-UFFI removal	p^a	Risk ratio
Nasal problem	28	35	0.04	1.3
Eye irritation	10	12	—	1.2
Tire easily	16	21	0.02	1.3
Throat discomfort	4	5	—	1.3
Increased thirst	4	6	—	1.5
Cough	8	13	0.04	1.6
Sputum	6	10	—	1.7
No. of subjects	605	699		

[a]Comparisons were made using the chi-square statistic.

Table 4. Decrease in symptoms related to number of days since remedial work done.[a]

Symptom	Slope	p
Nasal problem	0.0003[b]	0.03
Eye irritation	0.00002	0.9
Tire easily	0.00002	0.9
Throat discomfort	0.00004	0.7
Increased thirst	0.00001	0.9
Cough	0.0005	0.6
Sputum	0.0003	0.8
Headache	0.0003	0.02

[a]This analysis was based on occupants of all houses in which any form of remedial work was done.

[b]This slope indicates that there was a 0.3 percentage point decrease in the prevalence of nasal problem for each 10 days after remedial work was done.

Table 5. House variables.

Variable	Control		UFFI removal	
	Survey 1	Survey 2	Survey 1	Survey 2
Age of houses, years	33	—	41	—
Duration of UFFI, year	0	—	4.5	—
Socioeconomic	1.9	—	2.0	—
Day of year	258	253	211	208
Temperature outside	11	9	12	11
Smoking in house, %	52	47	46	41
No. cigarettes/day	9	7	7	7
UFFI removed, %	—	0	—	100
Wall cavities sealed, %	—	0	—	37
Ventilation added, %	—	1	—	10
Weatherproofing added, %	—	17	—	31
New pressed wood items, %	—	7	—	18
Formaldehyde, ppm				
Inside	0.035	0.036	0.046	0.044
Outside	0.005	0.007	0.006	0.007
Carbon dioxide, ppm				
Inside	742	719	697	746
Outside	345	333	347	348
No. of houses	209	209	241	241

Both groups of houses were similar in socioeconomic appearance. The day of the year of being assessed was similar within each group between the two surveys, but was about 6 weeks earlier in the year for the UFFI removal subset relative to the controls ($p = 0.0001$). This difference in time of year between the two groups was not associated with any appreciable differences in the ambient temperature at the time of being examined. There was an equally small decrease in the occurrence of smoking between surveys within both groups of houses.

The indoor formaldehyde levels were about 20% higher in the UFFI removal subset than in the controls ($p = 0.0001$) and did not change between the two surveys (Table 5). The outdoor formaldehyde levels were similarly low in both groups. The indoor and outdoor CO_2 levels were in the expected ranges and did not differ significantly either within or between the groups. Our inability to detect a decrease in formaldehyde in the removal subset at the second survey may have been related to the recent installation of pressed wood items, as well as some possible diminution in fresh air infiltration, which is suggested by the trend for the CO_2 level to increase in the UFFI removal subset at survey 2.

The frequency distribution of the indoor formaldehyde levels of the UFFI removal subset at the first survey was shifted rightward to a small degree relative to the controls, as would be expected from the difference between their means. This did not change appreciably at the second survey. There were five houses among the UFFI removal subset having mean indoor formaldehyde levels in excess of 0.112 ppm, whereas all in the control group were at this level or lower.

Exposure–response relationships were examined between the mean household formaldehyde level in the first survey of each house and the status of the various health indicators for each occupant. The UFFI removal subset at survey 1 showed a number of direct, significantly positive exposure–response relationships (Table 6). For example, for each 0.01 ppm of formaldehyde exposure, there was a 2.47 percentage point increase in the occurrence of nasal problems, a 1.15 percentage point increase in thirst, and a 1.13 point increase in cough. No comparable significantly positive relationships were seen among the controls.

Because the UFFI removal subset had a number of formaldehyde exposures that were higher than any in the control group, the same analysis was repeated after deleting those subjects with the higher formaldehyde exposures (Table 7). This showed a persistence but weakening of the exposure–response relationships when the 29 people were deleted whose exposure was greater than 0.112 ppm, and even when those 74 were dropped who were exposed to higher than 0.08 ppm, which overlapped the upper end of the range of exposure in the controls. When the exposure–response relationships were reexamined based on the second survey data for formaldehyde and health status indicators, no significant responses were observed (Table 8).

The findings of this study therefore indicate that health status indicators have improved and exposure–response relationships with formaldehyde have disappeared at the second survey, in the absence of any appreciable decrease in formaldehyde exposure relative to the first survey. Since these observations cannot be explained by a problem with our formaldehyde measurements, we

Table 6. Exposure–response relationships with formaldehyde based on survey 1.[a]

Symptom	Control		Pre-UFFI removal	
	Slope	p	Slope	p
Nasal problem	0.55	0.56	2.47	0.0001
Eye irritation	0.03	0.96	0.74	0.17
Tire easily	0.46	0.51	0.79	0.15
Increased thirst	0.30	0.45	1.15	0.007
Cough	0.49	0.37	1.13	0.02
Sputum	0.57	0.25	0.67	0.09

[a]Exposure–response relationships were examined by multiple linear regression analysis using health indicators as the dependent variable and mean household formaldehyde level as the predictor, as well as including age, gender, smoking experience, hours in house per week, and outside temperature as covariates. The analysis was done using data from the first survey on occupants who were also included in the second survey.

Table 7. Exposure-response relationships at survey 1, with subject inclusion dependent on level of formaldehyde exposure.

	Pre-UFFI removal formaldehyde levels included, ppm[a]			
Symptom	All p	< 0.113 p	< 0.08 p	< 0.06 p
Nasal problem	0.0001	0.002	0.003	0.12
Eye irritation	0.17	0.82	0.71	0.54
Tire easily	0.15	0.94	0.15	0.63
Increased thirst	0.007	0.08	0.03	0.14
Cough	0.02	0.18	0.05	0.70
Sputum	0.09	0.06	0.03	0.07
No. of subjects	699	670	625	550

[a]Subjects were included in the analysis in columns 2, 3, or 4 if the mean formaldehyde level in their houses at survey 1 was, respectively, below 0.113, 0.08, or 0.06 ppm. Eligibility was dependent on having participated in survey 2.

Table 8. Exposure-response relationships with formaldehyde based on survey 2.[a]

Symptom	Control p	Post-UFFI removal p
Nasal problem	0.17	0.07
Eye irritation	0.30	0.45
Tire easily	0.34	0.46
Increased thirst	0.64	0.24
Cough	0.98	0.15
Sputum	0.98	0.31

[a]This analysis was performed in the same manner described for Table 6, using survey 2 data for the same population.

are forced to conclude that the preremedial findings demonstrated at the first survey were not due to formaldehyde alone. These observations could be explained alternatively on the basis that formaldehyde interacted with some other chemical or psychological factors associated with UFFI, or was a proxy for them, and that they were removed by remedial work. If due to an interaction or proxy effect between formaldehyde and other UFFI-related chemicals, one might have expected to see a reduction in formaldehyde levels if removal of the UFFI was associated with a reduced exposure to the hypothetical other chemicals. Nevertheless, our results indicated a continuing source of the small excess of formaldehyde even after the removal of the UFFI, and thus this could continue to be associated with other related chemicals. Accordingly, we are unable to clearly distinguish whether this proposed interaction or proxy effect is between formaldehyde and other chemicals or psychological factors.

Conclusions

The results described show that in the first survey of the study population, before remedial work, there was a moderate excess of many adverse health status indicators among the UFFI subset relative to the controls. This was associated with the presence of direct exposure-response relationships between formaldehyde levels in the UFFI houses and the prevalence of a number of symptoms. No comparable exposure-response relationships were seen among the controls. At the second survey, performed following the removal of the UFFI, there was an appreciable reduction in the excess of most adverse health status indicators among the UFFI subjects relative to the controls. This improvement in health status among the UFFI removal subset was not associated with any significant diminution of formaldehyde exposures, although the previously observed exposure-response relationships had vanished. These observations are indicative of the complexities that may arise in assessing and understanding health risks in individual case studies related to chemicals in indoor air.

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